

IMPLEMENTING THE 2012–2021 NATIONAL GLOBAL CHANGE RESEARCH PLAN

USGCRP's [National Global Change Research Plan](#) and its [2017 update](#) provide the framework for advancing scientific understanding of the Earth system while strengthening capacity to answer questions critical to decision-making. The Program's four strategic goals, which align with its mandate under the GCRA, are to advance global change science, inform decisions, conduct sustained assessments, and engage key stakeholders and audiences in support of these goals, including internationally. This section highlights recent achievements that support implementation of USGCRP's goals and illustrate ongoing advances in the science of global change. Additional activities undertaken in the reporting period and in previous years are available at <https://www.globalchange.gov/explore>.

Advancing Science

Global change science covers a range of disciplines and methods, including Earth observations, Earth system modeling and predictability, understanding Earth system processes, and social science approaches to understanding the connection between human and natural systems. Data produced by USGCRP research efforts are made freely available for public use, and USGCRP and its member agencies have expanded their efforts to provide data in formats that are accessible and usable for decision-makers as well as scientists.

Integration across different topics and approaches, enabled by sustained interagency coordination through USGCRP, helps drive advances in understanding of the changing Earth system and ensure that federal science is able to inform decisions and actions in response to change. The research efforts highlighted in this section, drawn from diverse disciplines and methods within global change science, are advancing our ability to observe, understand, and model processes of change in the Earth system and inform efforts to build resilience to the impacts of global change.

Highlight 1. Unprecedented observations in the Southern Ocean help improve global climate models

The Southern Ocean surrounding Antarctica is the stormiest place on Earth, marked by heavy cloud cover that helps determine how much of the sun's energy reaches Earth's surface. Due in part to the scarcity of field data from the region, current climate models have difficulty reproducing the behavior of clouds over the Southern Ocean, which in turn affects how well they can simulate current and future climate. Motivated by these data limitations, an international multi-agency effort collected atmospheric and oceanographic data via ship-, aircraft-, and island-based instrumentation in a set of recent campaigns, revealing details about clouds, precipitation, and other atmospheric properties in the region that will help improve weather and climate modeling and forecasting capabilities across the globe.

Together, the NSF-funded [Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study](#) (SOCRATES), the DOE-funded [Macquarie Island Cloud Radiation Experiment](#) (MICRE) and [Measurements of Aerosols, Radiation and Clouds over the Southern Ocean](#) (MARCUS) campaigns, and the Australian Clouds, Aerosols, Precipitation, Radiation, and Atmospheric Composition over the Southern Ocean (CAPRICORN) program captured extensive observations of cloud and aerosol properties and flows of energy between the atmosphere and ocean between 2016 and 2018.

Measurements taken by different instruments will be integrated to reveal details about the atmosphere from the surface up to about 6 miles (10 km), ultimately providing highly detailed data that can be used to improve model predictions.

In addition to these focused interagency field campaigns, research and operational satellites operated by NASA and NOAA, respectively, provide information on the broader environment in which clouds form beyond the limited time periods of the campaigns. Together, data from focused field campaigns and ongoing satellite operations inform the larger-scale models that simulate Earth's climate system.



A researcher launches a radiosonde instrument attached to a weather balloon to capture detailed atmospheric data. Credit: National Center for Atmospheric Research.

Highlight 2. Scientists investigate the effects of carbon emissions from thawing permafrost soils

Long-frozen northern soils known as permafrost contain one of the world's largest stores of organic carbon. This reservoir is stable while frozen, but as permafrost thaws, decomposition of biomass by microbes produces the heat-trapping gases carbon dioxide and methane, returning soil carbon to the atmosphere where it contributes to climate change. Permafrost carbon stores are expected to be increasingly vulnerable to decomposition as the climate continues to change, leading to a feedback cycle of further warming and permafrost thaw.²

Earth system models have recently begun to account for the effects of carbon emissions from gradual, surface-level permafrost thaw in their estimates of future climate change. However, carbon emissions from processes of deeper, abrupt thawing that occur beneath thermokarst lakes—shallow ponds that form in permafrost terrain as soils thaw—are not yet accounted for in models. To help address this gap, researchers funded by NASA, NSF, and DOE used model output, supported

by USGS-NASA satellite data and field measurements, to investigate the impacts of carbon emissions from thermokarst lakes on future climate change.³

By comparing estimates of Arctic-wide permafrost carbon emissions from surface thaw alone with estimates that include abrupt thaw beneath thermokarst lakes, researchers found that accounting for emissions from abrupt thaw more than doubles previous estimates of warming caused by northern permafrost thaw this century. These findings demonstrate the need to incorporate abrupt permafrost thaw in Earth system models for a more comprehensive understanding of the rate of climate change throughout the 21st century.



Methane emitted from thawing permafrost below an Arctic thermokarst lake is trapped in bubbles of many different sizes and shapes as the ice grows during the winter. Credit: Katey Walter Anthony/University of Alaska Fairbanks.

Highlight 3. Researchers reconstruct a new history of ocean warming

Globally, average sea level has risen over the past several decades as ocean waters have warmed. While the ocean as a whole has absorbed a huge amount of heat from the warming atmosphere, ocean currents transport that heat differently across regions, contributing to significant regional variations in the amount of sea level change. Understanding changes in ocean heat content and the role of currents in shaping patterns of warming is critical to assessing current and future global and regional climate change, sea level rise, and coastal flooding risk.⁴

Before the 1990s, however, most ocean temperature measurements were limited to the upper ocean (above 700m), presenting an incomplete picture of past ocean heat content. To help address this gap, researchers funded in part by NASA combined NOAA and NASA satellite and field data with a model of heat transport within the ocean to reconstruct patterns of ocean warming over the industrial era. Their method pro-

vides a global, full-depth estimate of ocean warming dating back to 1871.⁵

The study also demonstrates that changes in heat transport by ocean circulation have produced significant regional variations in ocean heat content, and consequently, sea level rise. In particular, a stronger convergence of warm ocean currents in the Atlantic Ocean has contributed to the accelerated warming observed in the region over the past six decades. These findings show that analyses of ocean dynamics and circulation can help explain trends in ocean warming and sea level rise and yield clues about future climate and regional sea level change.

Highlight 4. New data infrastructure helps build a virtual ecosystem of Earth science information

The ability to archive and share datasets generated by field, experimental, and modeling activities is a critical component of Earth system and global change research. Several recent interagency efforts aim to support advances in global change data access, synthesis, and use.

DOE recently launched the [Environmental Systems Science Data Infrastructure for a Virtual Ecosystem](#) (ESS-DIVE), a publicly accessible archive of Earth and environmental science data generated by DOE-supported ecosystems research. ESS-DIVE enables the user community to easily access the datasets underlying research results, review results that have already been published, and use data for new analyses.

ESS-DIVE is a partner in the NSF-funded [Data Observation for Earth Network](#) (DataONE), which enables free and open sharing of scientific data across a platform of networked federal and non-federal data portals. DataONE supports enhanced search and discovery of Earth and environmental data across a number of repositories managed by its members, meaning that ESS-DIVE's data contents will be discoverable by a broader user base.

Together, these efforts broaden existing initiatives to help users efficiently access data that is easy to interpret, integrate, and analyze, enabling researchers to tackle critical global change research questions from a multi-disciplinary perspective.

Highlight 5. A collaboration identifies pathways to enhance social science integration in federal global change research

Through its Social Science Coordinating Committee (SSCC), USGCRP works to integrate social science methods, findings, and disciplinary perspectives into federal global change research programs. The social, behavioral, and economic sciences provide critical insights on the drivers and impacts of global change and inform mitigation, adaptation, and resilience decisions.

In February 2019, in collaboration with the National Academies of Sciences, Engineering, and Medicine's Board on Environmental Change and Society, the SSCC convened a seminar entitled "Climate Resilience Pathways and Social Science Research Actions." Building on a [March 2017 workshop examining social science perspectives on climate change](#) and [the subsequent publications](#), the seminar brought together over 200 participants from academia, federal agencies, and diverse state, local, and civil society stakeholders. Participants discussed opportunities to advance interdisciplinary research in federal programs,

and the use of social science research and insights for societal transformation to meet global change and sustainability challenges.

The seminar presented recent interdisciplinary social science syntheses for understanding societal drivers of and vulnerability to climate change, and effective responses that consider a variety of socio-cultural and historic contexts. Academic researchers and federal agency and international program managers discussed the successes and challenges of social science integration and interdisciplinary and transdisciplinary approaches in global change research and decision support. The seminar and subsequent discussions identified areas for potential future work, including enhancing institutional infrastructure to foster federal and academic interdisciplinary collaboration, and connecting social science research with the environmental justice community and decision-making.

Informing Decisions

USGCRP coordinates and integrates efforts across the Federal Government to provide access to authoritative, freely available assessments, datasets, and tools that inform decisions related to all aspects of global change. Interagency science contributes to the development of information tools for responding to climate-related risks and opportunities, including the provision of information at regional scales useful for decision-making.

Highlight 6. Interagency data products and research inform hurricane response and recovery in the Carolinas

Hurricane Florence struck the Carolinas on September 14, 2018, causing widespread flooding and damage. In the aftermath of the storm, NASA deployed airborne radar to [map floodwaters threatening the region](#), supplying federal, state, and local agencies with information critical to disaster response efforts.

Airborne radar is able to "see" through cloud cover to image the ground below during day and night and can map flooding occurring under vegetation, which is especially valuable in heavily vegetated areas such as the Carolinas. Scientists rapidly mapped the extent and depth of flooding, helping local authorities identify potential damage to and blockage of infrastructure such as roadways and levees and prioritize recovery efforts as flood waters receded.

NASA worked closely with and leveraged the expertise of state, federal, and other partners to provide analysis of satellite imagery, data products, and other decision-support aids, including the states of North Carolina and South Carolina, the Federal Emergency Management Agency, Federal Aviation Administration, U.S. National Guard, U.S. Geological Survey, NOAA, USDA-Forest Service, the University of South Carolina, and the University of Florida.

Following the immediate focus on response and recovery, satellite and airborne observations are helping scientists update streamflow and flood models. In particular, measurements of flood level change will assist NOAA and NASA hydrologists in updating flood prediction models.



This image of Pee Dee River in South Carolina was captured by NASA's *Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)* instrument aboard a September 17, 2018 science flight. The color composite image shows extensive water inundation, which is visible as various shades of pink pixels, along the present-day river and old river bed across a broad area of 8 to 10 km. Black: flooded ground, smooth bare ground (e.g., roads), or open water (e.g., river). Pink: flooded vegetation. Green: vegetation. Brightness indicates the strength of radar backscatter. Credits: NASA/Google.

Highlight 7. Drought and wildfire research supports adaptation planning in the western United States

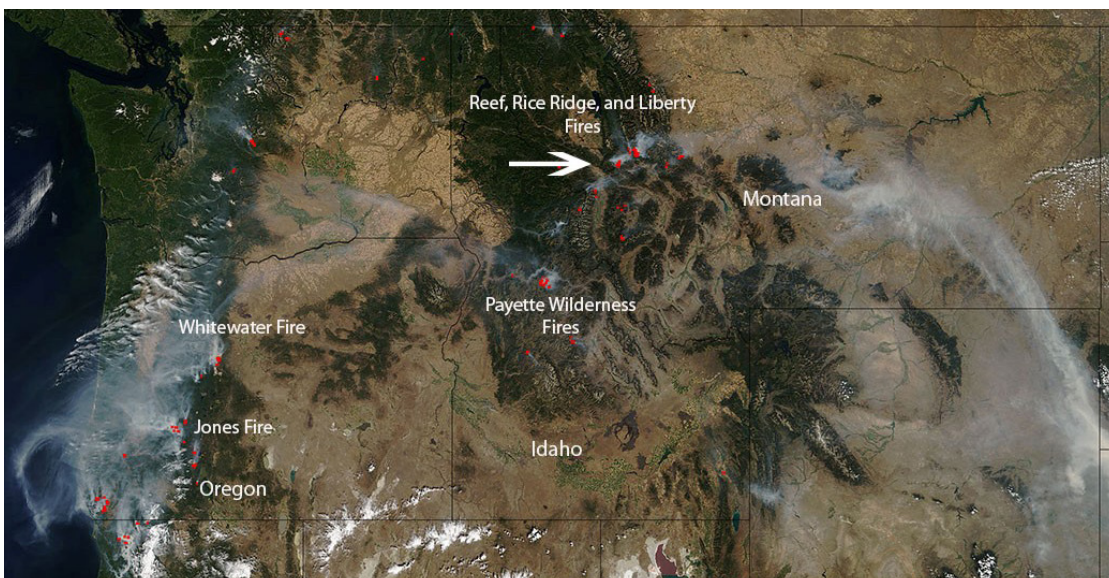
Wildfires affect communities throughout the United States each year, threatening lives, property and infrastructure, and ecosystems.⁶ Understanding how climatic conditions influence wildfire patterns can improve our ability to predict the occurrence and severity of future wildfires, and ultimately support the development of effective adaptation strategies.

In response to this need, multiple programs within the U.S. Geological Survey (USGS) and the Department of the Interior's [Climate Adaptation Science Centers](#) (CASC) are collaborating with the USDA Forest Service (FS) and other partners to deliver the data needed to understand and plan for changes in wildfire risk. [Several papers published in 2018](#) describe results from efforts funded by the Alaska CASC that included use of climate model data supported by DOE, NOAA, and DOI, and wildfire data from USDA-FS and DOI.

Researchers supported by USGS and USDA-FS investigated how future changes in climate might affect area burned in different types of ecosystems in the western United States, producing data at scales relevant for watershed and landscape manage-

ment.⁷ While results suggest that area burned will continue to increase on a regional level, outcomes for individual landscape types vary. Area burned is expected to grow in forests and some areas with a mix of forests and non-forest vegetation, but decrease in some (though not necessarily all) drier non-forested ecosystems with limited fuel. However, because of changes in other factors that influence wildfire (such as land use, fire suppression practices, or invasive species) that can be difficult to anticipate, these projections do not represent long-term forecasts.

In another project, a USGS researcher examined the current understanding of the relationship between wildfire and drought, and recommended key research directions aimed at increasing the usefulness of that knowledge for managing fire risk.⁸ Information on how climate conditions and drought influence wildfire over different timescales, along with a greater understanding of how people affect and respond to wildfires in the longer term, could ultimately result in predictions of the timing and size of future wildfires for use in regional planning.



A natural-color image captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite on August 27, 2017 shows dozens of wildfires burning in the western United States. Credit: Jeff Schmaltz/NASA Goddard Space Flight Center.

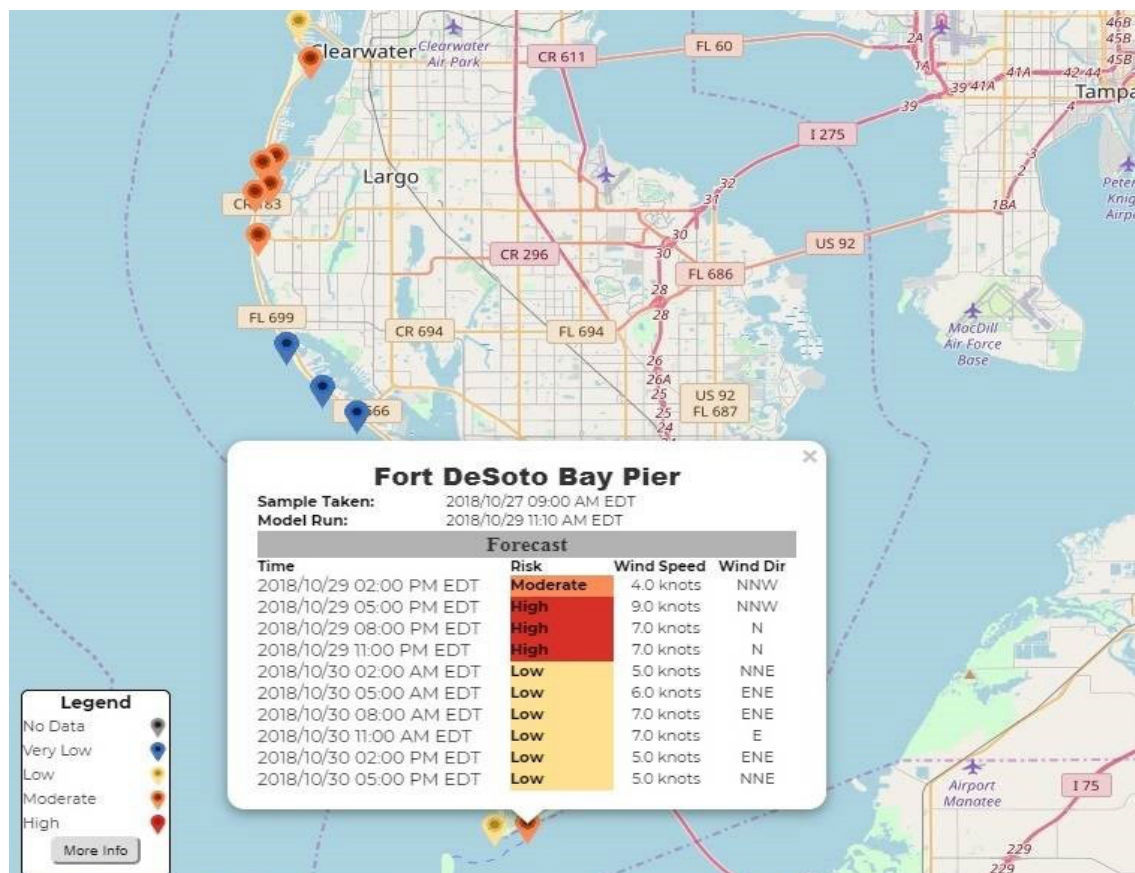
Highlight 8. A new forecast tool helps the public avoid toxic algal blooms

In the Gulf of Mexico, toxic algal bloom outbreaks (or red tides) occur primarily during the late summer and early fall, and can be harmful to people and ecosystems. One of the most severe red tide outbreaks in a decade hit Florida's Gulf Coast throughout the summer and early fall of 2018, with widespread adverse impacts that prompted the governor to declare a State of Emergency in mid-August.

In October 2018, a new pilot smartphone-based information resource developed by NASA, NOAA, and state and local partners began alerting users to red tide risks around St. Petersburg and Pinellas County, Florida. The new 24-hour Experimental Red Tide Respiratory Forecast is updated every three hours and allows the public to see which beaches are currently impacted

by red tide and which ones may be impacted over the next day. The forecast system uses satellite data to identify and map the spatial extent of algal blooms, as well as water sampling to test for the presence of toxic blooms.

The tool was developed by NOAA's National Centers for Coastal Ocean Science in partnership with the Gulf of Mexico Coastal Ocean Observing System, the Florida Fish and Wildlife Conservation Commission, and Pinellas County Environmental Management, through funding from NASA. It builds on NOAA's Harmful Algal Bloom Forecast System and the Near Real-Time Integrated Red Tide Information System from the University of South Florida, both of which use NASA satellite data from the Terra and Aqua spacecrafts.



An image from a new pilot smartphone-based information tool that alerts users in Florida's central Gulf Coast to potential respiratory hazards from toxic algal blooms. Credit: Gulf of Mexico Coastal Ocean Observing System.

Highlight 9. Flood mapping helps planners visualize the future of California's coast

U.S. coastal communities are increasingly vulnerable to sea level rise, tidal flooding, higher storm surge, coastal erosion, and other climate-related impacts.⁹ To help communities in southern California plan for rising water levels, a NASA [DEVELOP](#) team collaborated with the U.S. Geological Survey's (USGS) Pacific Coastal and Marine Science Center, in partnership with the California Coastal Commission, to create detailed projections of flooding from sea level rise and coastal storms along the central and southern California coastline that can inform planning to reduce climate-related risks to future development.

The team updated USGS's online coastal flood prediction tool, the [Coastal Storm Modeling System \(CoSMoS\)](#), using data collected via aircraft and satellite (including the [Uninhabited Aerial Vehicle Synthetic Aperture Radar \(UAVSAR\)](#) mounted on NASA aircraft and the [Landsat 8](#) satellite) to create more detailed flood projections for the central and southern Cal-

ifornia coastline. The team focused on very high tide events, known as king tides, that already cause regular flooding in some low-lying communities in southern California, offering a preview of events that communities can expect to occur more frequently as sea level continues to rise. The updated data allowed the project team to see details from particular king tide events and generate a new baseline for the impacts of future king tides along the southern California coastline.

Using the new satellite and aircraft data, USGS plans to assess the accuracy of and update flood simulations provided by CoSMoS, which, in turn, will provide better flood hazard forecasts for southern California communities. The updated data are among the resources the California Coastal Commission will use as a guide for identifying areas likely to be affected by flooding and erosion as sea level continues to rise.



A king tide flooded parts of Imperial Beach, California in December 2018. Credit: California King Tides Project.

Conducting Sustained Assessments

As required by the Global Change Research Act, USGCRP produces a quadrennial National Climate Assessment (NCA) that synthesizes understanding of present and future climate change processes and the ongoing and potential impacts on society in the United States. Since the release of the [NCA3](#) in 2014, USGCRP has transitioned towards a sustained assessment process that supports ongoing assessment and engagement processes, culminating in a quadrennial assessment, the most recent of which was completed in 2018 (Highlight 10). Through sustained assessment efforts, agency and interagency assessment products provide valuable inputs to the NCA, including the [Second State of the Carbon Cycle Report](#) released in 2018 (Highlight 11), and serve individual agency and interagency constituencies.

Highlight 10. Assessment products outline climate-related risks and response actions

USGCRP completed the Fourth National Climate Assessment (NCA4) in November 2018 with the release of NCA4 Volume II ([Impacts, Risks, and Adaptation in the United States](#)). Building on an assessment of observed and projected changes in the physical climate system released as Volume I of NCA4 ([Climate Science Special Report](#)) in 2017, Volume II focuses on climate-related risks to systems that support our well-being and economy.

A number of ongoing assessment products and efforts undertaken by USGCRP's member agencies and interagency groups provided valuable inputs to NCA4 Volume II. USGCRP led the development of two major sustained assessment products that served as inputs to the report: [The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment](#) and the [Second State of the Carbon Cycle Report](#) (see Highlight 11). A number of USGCRP agency-led products also improved the thoroughness of the assessment, including the USDA-led assessment on [Climate Change, Global Food Security, and the U.S. Food System](#) conducted on behalf of USGCRP, and [Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis](#); NOAA's [Climate Resilience Toolkit](#), [Climate Explorer](#), and [State Climate Summaries](#); and EPA's updated [economic impacts of climate change report](#). In addition, a variety of USGCRP [indicators](#) and [scenario products](#) supported the evaluation of climate-related risks throughout the report's regional and sectoral chapters, and the report's Overview chapter featured an interactive graphic on [climate-relevant indicators based on data collected around the United States](#).

Both volumes of NCA4 are supported by the [Global Change Information System](#) (GCIS), a freely accessible database linking together all the information used in USGCRP assessments. GCIS acts as an advanced, multifaceted bibliography for the more than 6,000 unique references cited across the 29 chapters of Volume II, maintaining easy-to-find records of the sources of all scientific information in the report and providing access to the original data and research. This includes analysis and visualization processes for figures, enabling reproducibility and transparency of results. GCIS also supports other USGCRP sustained assessment products.

NCA4 Volume II was authored by more than 300 federal and non-federal experts, including individuals from federal, state, and local governments; tribes and indigenous communities; national laboratories; universities; and the private sector. The entire process was informed by engagement with hundreds of external stakeholders, including a series of regional workshops that reached more than 1,000 individuals in over 40 cities. Listening sessions, webinars, and public comment periods also

provided valuable input to the authors. The report underwent an extensive, multi-phase process of review—involving the submission of and response to nearly 10,000 review comments—received from USGCRP federal agency experts, the general public, and a panel of experts from the National Academies of Sciences, Engineering, and Medicine.

NCA4 Volume II is available at nca2018.globalchange.gov.



Increasing heavy rains are leading to more soil erosion and nutrient loss on midwestern cropland. Integrating strips of native prairie vegetation into row crops has been shown to reduce soil and nutrient loss while improving biodiversity. The inset shows a close-up example of a prairie vegetation strip. Source: Figure 21.2, Ch. 21: Midwest, NCA4 Volume II (Photo credits: [main photo] Lynn Betts; [inset] Farnaz Kordbacheh).

Highlight 11. A major interagency assessment evaluates carbon cycle science and impacts on society

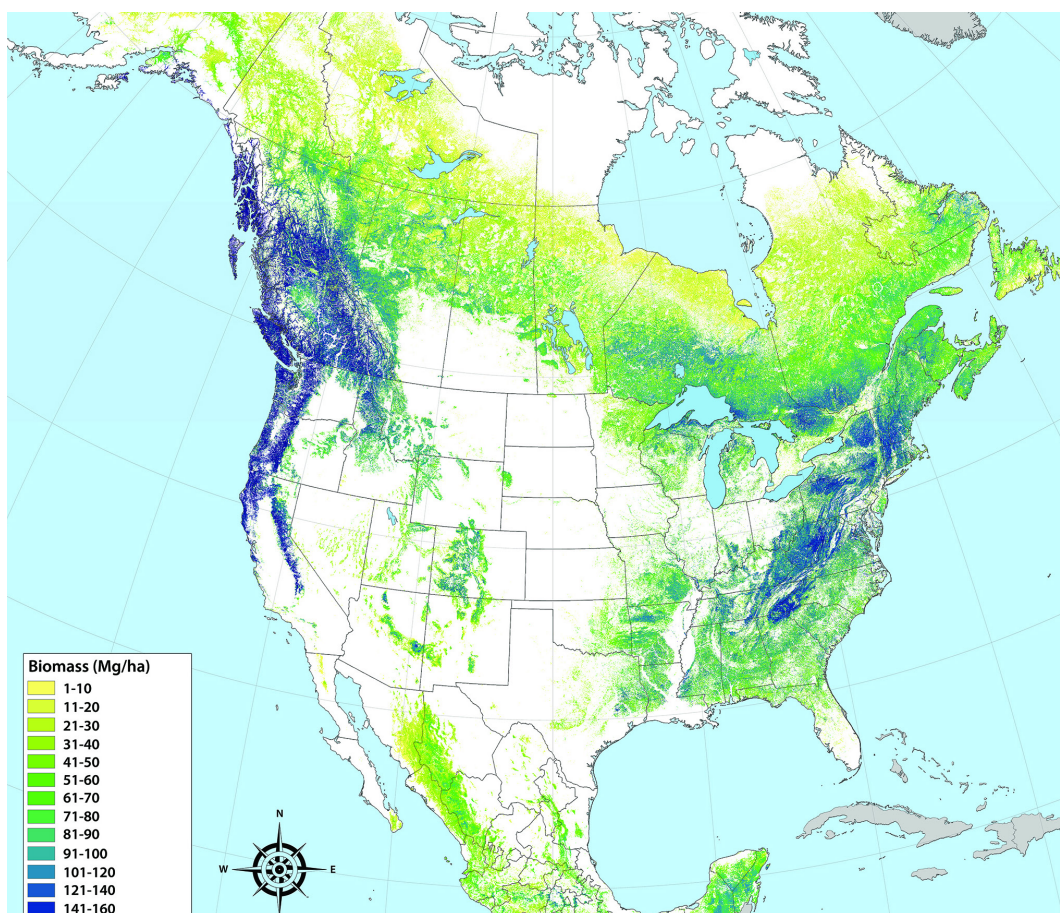
The [Second State of the Carbon Cycle Report](#) (SOCCR2), released by USGCRP in November 2018, is a state-of-the-science assessment of the carbon cycle in North America and its connection to climate and society. Authored by more than 200 experts from the United States, Canada, and Mexico, SOCCR2 focuses on U.S. and North American carbon cycle processes and their interactions with global-scale carbon budgets and climate change impacts over the last decade.

The report includes an assessment of carbon source, sinks, and flows across atmospheric, aquatic, and terrestrial systems, including natural and managed ecosystems and human systems such as agricultural production. Responding to the needs of stakeholder groups such as natural resource managers, it con-

siders relevant carbon management science perspectives and science-based tools for supporting and informing decisions in the context of a changing climate. SOCCR2 also evaluates the status of and emerging opportunities for improving measurements, observations, and projections of carbon cycle change in North America.

SOCCR2 underwent an extensive, multi-phase process of internal and external review from federal agency experts, the general public, and a panel of experts from the National Academies of Sciences, Engineering, and Medicine.

SOCCR2 is available at carbon2018.globalchange.gov.



This image shows the distribution of aboveground forest biomass across North America, measured as milligrams of biomass per hectare (mg/ha). One hectare is equivalent to about 2.5 acres. This map combines four independently developed maps of biomass for Canada, Alaska, the conterminous United States, and Mexico. Source: SOCCR2, Figure 9.1.

Supporting International Global Change Science

As part of its mandate under the Global Change Research Act, USGCRP works to improve coordination of U.S. activities with the programs of other nations and international organizations in order to promote international cooperation on global change research and build global change research capacity in developing countries. To advance these goals, USGCRP develops international partnerships that support the priorities and objectives of the USGCRP community, link to USGCRP's program areas, and build on existing agency investments and resources. The partnerships and related activities highlighted this year support activities that align with USGCRP's strategic goals and help to maintain U.S. influence and leadership in the international research community.

Highlight 12. A new collaboration on data and decision-making supports sustainability in the Amazon Basin

[SERVIR](#) is a joint initiative between NASA and USAID that develops demand-driven services, tools, and training for decision-makers in more than 50 countries. By connecting USAID's development network with NASA's science, geospatial technologies, and extensive satellite data, SERVIR helps strengthen local capacity to integrate science and technology into decision-making.

Since 2004, SERVIR has collaborated with leading regional organizations in the developing world to help people and insti-

tutions track environmental changes, evaluate climate threats, and respond rapidly to natural disasters. In March 2019, USAID and NASA initiated activities for [SERVIR-Amazonia](#), a five-year effort that will address environmental and development challenges in the Amazon Basin, home to the world's largest tropical rainforest. SERVIR-Amazonia will be one of five SERVIR regional hubs currently operating around the world, and will be implemented through a network of local and international partners serving the Amazon region.

Highlight 13. Interagency efforts help lead a new international climate and health research initiative

USGCRP agencies and interagency groups played a leading role in the development of a Belmont Forum international Collaborative Research Action (CRA) launched in April 2019, focused on issues at the intersection of climate, environment, and human health.

In addition to an international scoping workshop organized by the Interagency Crosscutting Group on Climate Change and Human Health (CCHHG) and International Activities Interagency Working Group (IAIWG) in April 2018, USGCRP member agencies (including the National Institutes of Health (NIH), NOAA, and NSF) participated in a year-long, international drafting process for a final research call. USGCRP member agencies (including NIH, NOAA, NSF, and USDA) also partnered on the CRA by providing funding or in-kind contributions to support

eligible U.S. researchers. Following the Belmont Forum model, U.S. resources would directly support only U.S. researchers as part of this action. However, this opportunity allows U.S. agencies to leverage the contributions of other international partners and promote scientific collaboration.

The CRA will support international research teams of natural, health, and social scientists and stakeholders, working together to understand how climate variability and change influence human health and well-being, and to support effective responses. The initiative aims to generate scientific evidence and tools to support policy and decision-making that can enhance health system resilience to climate impacts and provide significant public health benefits.

Highlight 14. USGCRP supports major international global change assessments

USGCRP coordinates and supports the engagement of the U.S. science community in major international assessments on global change science, including those conducted by the Arctic Monitoring and Assessment Programme, the Intergovernmental Panel on Climate Change (IPCC), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), as well as science panels informing the Montreal Protocol on Substances that Deplete the Ozone Layer process.

International assessment reports provide policymakers with regular updates on the state of knowledge, current and future risks, and potential response options to climate change, biodiversity loss, and other drivers of global environmental change. Scientists affiliated with and supported by USGCRP are key contributors to major assessments as authors and reviewers, providing technical support and scientific expertise.

In collaboration with the State Department, USGCRP provides support for U.S. author participation in and U.S. government review processes for these assessments. In addition, USGCRP

member agencies support scientific observations and model projections that serve as key inputs into assessment deliverables. In 2019, IPBES published a major global assessment, and IPCC released two Special Reports requested by governments as part of the Sixth Assessment Report cycle.